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Asian openbill stork *Anastomus oscitans* as a predator of the invasive alien gastropod *Pomacea canaliculata* in Thailand

La cigüeña asiática de pico abierto *Anastomus oscitans* como un depredador del caracol manzana *Pomacea canaliculata*, especie exótica invasora en Tailandia

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ABSTRACT

The freshwater golden apple snail *Pomacea canaliculata*, native to South and Central America, and the West Indies, is now a major agricultural pest in Thailand paddy fields. There is anecdotal evidence that the Asian openbill *Anastomus oscitans* consumes these snails, but no reports on its predation efficiency. Our study showed that the number of storks visiting the fields correlated with a decrease in snail abundance (r_s= 0.902, p= 0.0001). Storks are tactile predators and preferred adult snails. This is probably more profitable for the birds, but keeps the *P. canaliculata* population 'sustainable'.

RESUMEN

El caracol manzana dorado *Pomacea canaliculata*, una especie de agua dulce originaria de América del Sur y Central y del Caribe, es actualmente una plaga agrícola importante en los arrozales de Tailandia. Se sabe que las cigüeñas asiáticas de pico abierto *Anastomus oscitans* consumen estos caracoles, pero no hay datos sobre la eficacia de esta predación. En este trabajo se muestra que hay una correlación entre el número de cigüeñas que visitan los arrozales y una disminución en la abundancia de caracol (r_s= 0,902, p= 0,0001). Las cigüeñas son depredadores táctiles y prefieren caracoles adultos. Esto es probablemente más rentable para las aves, pero mantiene la población de *P. canaliculata* en niveles "sostenibles".

INTRODUCTION

Golden apple snails *Pomacea canaliculata* (Lamarck, 1822) are freshwater gastropod molluscs originally native to South America, Central America, and the West Indies (Pain, 1972). They were first introduced into Taiwan in Asia in 1979-80, to be cultivated as a high-protein food source for local people and export to industrialized countries (Naylor, 1996). Subsequently, they were

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introduced to other Asian countries, including Japan, the Philippines, China, South Korea, Malaysia, Thailand, Indonesia and Vietnam. In Thailand, *P. canaliculata* were first imported in 1982-83, probably from Japan, Taiwan and the Philippines via Chatuchak weekend market for culturing as aquarium pets. These snail farms were subsequently abandoned, allowing the snails to invade all natural freshwater environments and become a serious pest in paddy fields, particularly in central Thailand (Janyapeth and Archawakom, 1998).

P. canaliculata is a dioecious, sexually dimorphic gastropod, with mature males smaller than mature females (Sitti, 1988; Estebenet and Cazzaniga, 1998). Reproduction is continuous in tropical zones (Martín, Estebenet and Cazzaninga, 2001) and begins at ages of 2-3 months after hatching (Cowie, 2002) or when they have reached a size of > 25 mm (Sawangproh unpubl data). Mating occurs at any time of the day and in all seasons of the year, as long as there is a sufficient supply of water (Naylor, 1996). Females can lay eggs weekly, on substrates from the bare ground of canal banks to vegetation above the water line. Clutch size varies from 400-3000 eggs, depending on the availability of food and the size of the reproductive female (Sitti, 1988; Janyapeth and Archawakom, 1998), indicating that control of snails of reproductive age may be an effective control strategy. The control of apple snails as agricultural pests using various biological control agents has been extensively reviewed (egrets - Acosta and Pullin, 1989; firefly larvae - Kondo and Tanaka, 1989; water bugs - Aroonsrimorakot, 1993; fish - Halwart, 1998; fire ants - Yusa, 2001; carp - Ichinose, Tochihara, Wada, Suguiura and Yusa, 2002; leeches - Aditya and Raut; 2005). However, studies of other organisms that prey on apple snails are still needed.

Common large waders foraging in paddy fields and irrigation canals in central Thailand include herons and egrets (Ardeidae), and a stork species the Asian openbill *Anastomus oscitans* (Boddaert, 1783) that feeds exclusively on mollucs, especially the large native freshwater apple snails *Pila* spp. (Kahl, 1971; McClure, 1974; Lauhachinda 1969; Lekagul and Round, 1991; Poonswad, 1979). However, in response to the spread of the alien *P. canaliculata* in the aquatic environment, the native *Pila* snail population has decreased (Lauhachinda, Senawong, Phongsmas, Udomchoke, Homchan and Makatan, 1999) and the Asian openbill has shifted its diet from *Pila* (Poonswad, 1979) to *P. canaliculata* snails (Khobkhet, 2000). The Asian openbill is believed to be the most effective natural predator of *P. canaliculata* (Khobkhet, 2000 and various farmers pers. comm.). The objectives of this study were to determine the feeding behavior of the Asian openbill on *P. canaliculata* and assess its efficiency as a predator on these snail populations in paddy fields of central Thailand.

MATERIALS AND METHODS

Study area

The study was conducted in Nakhon Pathom Province (14° 00′ N; 100° 14′ E) in central Thailand, where *P. canaliculata* infestation is severe. We conducted our studies on various paddy field blocks, each about 2 acres in area, that occurred alongside 16-20 km of the local road No. 3004 just north of Salaya Campus, Mahidol University (13° 50′ N; 100° 18′ E). We also studied snail abundance and size in Donthong Village (DT; 13° 47′ N; 100° 16′ E) and Sanchao Village (SC; 13° 50′ N; 100° 16′ E), which are about 6 km apart and where no storks had ever been sighted.

Flock size and feeding behavior of storks

We counted the number of storks at 25 blocks of paddy fields along road No. 3004 and recorded their feeding behavior at first sighting through 10x binoculars.

Figure 1. Varying sizes of empty shell of *P. canaliculata* snails left in the paddy fields after stork foraging (H= height; W= width).

Figura 1. Distintos tamaños de conchas vacías de caracoles P. canaliculata *abandonados en los campos de arroz después de excursiones alimenticias de la cigüeña (H= altura, W= anchura).*

Snail abundance and measurement

We distinguished snails that were recently consumed by storks from those that had died earlier, either from stork predation or other causes by looking at the fresh muscle remaining attached to their shells and opercula, or at visceral masses and reproductive organs, such as albumen, found near the shells. We measured the size i.e. height and width of live snails to the nearest 0.01 mm using vernier calipers and then returned them to the same fields, whereas dead shells were brought to the laboratory for measurement (Figure 1). We also studied snail abundance and size in DT and SC.

Effects of storks on snail abundance and size

To determine the effect of the storks on snail abundance, we studied the flock sizes of the storks and snail densities at another seven blocks of paddy fields along road No. 3004, over ten consecutive weeks from late February to April 2006. To determine the effect of Asian openbill predation on snail sizes, we randomly sampled live snails and preyed-on shells using quadrat sampling (quadrat size= 1x1 m, n= 20) after the storks had been feeding in the seven paddy fields from July-April 2006. All paddy fields visited were at the phase of field preparation for rice planting, when rice stalks are burnt and the fields flooded.

Statistical analysis

We analyzed flock sizes of Asian openbill quantitatively and their feeding behavior descriptively. To determine the efficiency of stork in controlling snail populations, we plotted the percentage of snails preyed on by storks against the number of storks visiting each field. Based on flock size, we classified our 25 paddy fields during this study into three classes: 1) 12 low openbill-pressure sites, where visits by storks were known to be frequent but with low abundance (mean flock size 16.4 ± 15.3 storks/flock, n= 12), 2) 13 high openbill-pressure sites, where stork visits were known to be frequent and abundance high (53.0 ± 31.8 storks/flock, n= 13), with 3) one stork-free site (DT-SC) as control. We classified the data of snail sizes from all these paddy fields and correlated them with the three distinct classes based on stork abundance and frequency of stork visit. We categorized the snails into 2 size-classes on their reproductive potential: a) juvenile or non-reproductive (≤ 25 mm high) and adult or mature (> 25 mm high; based on CARLSON, BRÖNMARK, AND HANSSON (2004). Finally, using the Goodness of fit test, we determined snail size preferences as consumed by storks.

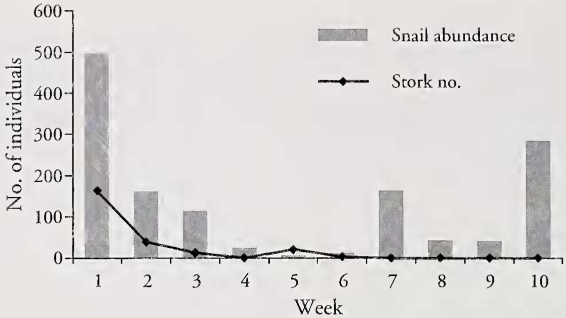

Figure 2. Seven paddy fields showed decreasing snail abundance corresponding to the numbers of foraging storks except the last four weeks when snails were brought into the fields accompanied by water flooding.

Figura 2. Siete arrozales mostraron una disminución de la abundancia de caracoles correspondiente al número de cigüeñas alimentándose, con la excepción de las cuatro últimas semanas, cuando más caracoles fueron llevados a los campos acompañados por inundaciones.

RESULTS

Abundance of the Asian openbill and its feeding behavior

Flock sizes of storks visiting the paddy fields ranged from 6-133 storks per flock (39.5 ± 30.5 storks/flock, n= 24). Stork feeding sites were characterized by flooded fields with water depth ranging from 2.3-16.0 cm (6.4 ± 3.4 cm, n= 24). The flock sizes of storks were positively correlated with snail abundance (live and preyed-on snails) in the fields (r_s= 0.6112, p= 0.0082).

We observed that storks searching for snails probed with their bills under and adjacent to floating vegetation and rice stalks. The stork slightly opened its bill and stabbed through the water. When a snail was located, the stork quickly closed its bill, pinned the snail to the ground with its mandibles and then pushed the tip of the lower mandible in to open snail operculum. Once the operculum was opened, the stork then inserted its mandibles, lifted up the snail, shook its bill to free the snail's body from its shell, swallowed the flesh and discarded the shell and operculum.

The effect of the Asian openbill on snail abundance

Snail abundance at seven paddy fields decreased in tandem with decreasing numbers of visiting storks, except during the last four weeks of the study when the fields were flooded with water by farmers, bringing new snails from nearby irrigation canals to settle in the fields (Figure 2). In addition, we found that the percentage of preyed-on snails was positively related to the number of visiting storks (r_s= 0.902, p= 0.0001).

The effect of Asian openbill predation on snail sizes

Storks took a longer time (61.0 ± 50.7 seconds, n= 9) to successfully extract large-sized snails (63.2 ± 10.99 mm in length, n= 80) comparing to the few seconds required to swallow each small-sized snail. Storks apparently preferred large-sized (= mature adult) snails to juvenile (= immature small-sized) snails (Table I).

DISCUSSION

Abundance of Asian openbills and their feeding behavior

The flock size of storks varied depending on *Pomacea* snail abundance. All paddy fields visited by storks were burnt and then flooded shortly afterwards. At this time, the habitat allows snails to come out of their hibernating burrows, grow and reproduce, making them available to storks in the fields. We observed

Table I. Summary of snail abundance, preference of snail sizes chosen by storks, and total number of storks at three different sites. (juvenile= immature, adult= mature)
Tabla I. Resumen de abundancias de los caracoles, tamaños de los caracoles preferidos por las cigüeñas, y número total de cigüeñas en tres sitios diferentes. (juvenil= inmaduro; adulto= maduro).

Site	Snail density (nos / 20 m^2)	Nº of snails (abundance)	% abundance	Nº of snails preyed on	% preyed on	χ^2	Total nº. storks
The no-stork DT-SC site							
Juvenile (≤ 25 mm)	50	99	32.3	92	15		
Adult (> 25 mm)	104	481	67.7	325	53		
Total	154	617	100	417	68	59.71 (P < 0.001) df= 1	200*
12 low-stork site2							
Juvenile (≤ 25 mm)	64	445	55.1	215	27		
Adult (> 25 mm)	52	362	44.9	240	30		
Total	116	807	100	455	57	25.53 (P < 0.001) df= 1	197
13 high-stork sites							
Juvenile (≤ 25 mm)	74	898	69.6	193	15		
Adult (> 25 mm)	32	393	30.4	264	20		
Total	106	1291	100	457	35	247.48 (P < 0.001) df= 1	688

* Storks visited the site for the first time in several years due to ongoing clearing of previously surrounding orchards.

storks repeatedly visiting the same paddy fields when snails were available, but not fields with high, dense rice stalks where it was possibly difficult to find snails. When searching for snails, the stork probes with its bill in shallow water with the tips of the mandibles slightly open, griping a snail once found and then withdrawing its soft body from the shell. This foraging method is known as tacto-location (COULTER, BALZANO, JOHNSON, KING AND SHANNON, 1989) and is similar to snail-locating behavior in limpkins *Aramus guarauna* (Linnaeus, 1766) (SNYDER AND SNYDER, 1969). Extraction of *Pila* snails by Asian openbill is the same as described by KAHL (1971) where the tip of the lower mandible is usually inserted into the shell and the body dislodged without help from the feet. When feeding on native *Pila* or exotic *P. canaliculata* snails, Asian openbills did not damage the shells from these observations. We also observed Asian openbills discard the albumen glands of mature female snails on the ground where they fed. Possibly, the yolk and eggs of this snail are distasteful, as suggested by SNYDER AND KALE (1983), and the yellowish albumen conspicuous and presumably aposematic to avian predators.

The effect of Asian openbills on apple snail abundance and snail size

Large flocks of openbills could greatly reduce snail populations in paddy fields. Even though the cost of handling, extracting, and consuming large-sized snails was high compared to small-sized snails, storks preferred to eat large-sized snails, apparently because large-sized snails gave more profitability (more energy returns) as predicted by optimal foraging theory (PYKE, 1984). Small-sized snails, which openbills swallowed whole, included much more indigestible material (hard shells and corneous opercula), than the large-sized snails where openbills left the hard shells (Figure 1) and tough opercula in the fields.

The preference for large-sized or adult snails by openbills may negatively affect the reproductive success of the snails, and consequently their population dynamics. On the other hand, the remaining small-sized snails are allowed to grow and reproduce, incidentally making the population a 'sustainable' food source for the storks. Overall, openbills were considered effective agents in controlling the snail population while crops were present; particularly those of reproductive size that would cause most crop damage (Table I).

The limpkin, a tactile predator like the Asian openbill, acts as an agent of disruptive selection on *P. paludosa* snail size by selecting average-sized snails disproportionately more often than small or large snails (Reed and Janzen, 1999). Snail kites *Rostrhamus sociabilis* (Vieillot, 1817), which feed exclusively on *P. paludosa* snails in their native range in Florida, Venezuela, and Colombia, search for prey visually (Beissinger, 1983, 1990; Snyder and Kale, 1983) and seemed to be agents of directional selection against lighter colored snails (Reed and Janzen, 1999). From our observation, storks evidently showed size preference for adult snails over juvenile snails at every study site (Table I).

CONCLUSIONS

The Asian openbill, a resident bird, is an important predator of the mature stage of the invasive alien golden apple snail in Thailand, where rice planting is practiced all year round. Based on snail size and abundance, openbills could potentially feed on and then lower snail population of all sizes, but preferred the large-sized snails that were probably of a more profitable size.

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